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ABSTRACT: The aim of this study was to examine changes in time-motion patterns of elite male ice hockey players during an international game with special reference to the development of fatigue. Ten elite male ice hockey players were filmed during an official international game. Detailed time-motion patterns and behaviours (effective playing, stoppage and resting times, number of shifts, low- and high-intensity skating activities across periods as well as passing, shooting and body checking) were analysed during the three game periods. Shift duration averaged 85.72±4.89 s (44.01±5.71 s of effective playing time and 41.71±4.07 s of stoppage) and was repeated ~7.4±1.8 times per period. Mean effective playing time and effective time per shift decreased over the periods (-6.8±17.3%, P = 0.18, *d* = 0.71 and -8.5±12.7%, P = 0.20, *d* = 0.24, respectively), resulting in a shorter distance covered (-12.8±5.7%, P = 0.16, *d* = 0.46) from period 1 to 3. At similar time intervals, stoppage (+8.2±9.8%, P<0.05, *d* = 0.78) and bench resting period (+35.6±34.0%, P<0.05, *d* = 1.26) also increased. The number of sprints performed in period 3 was significantly lower than in period 1 (-46.7±32.1%, P<0.01, *d* = 1.12). This was accompanied by a lower effective time (-16.8±24.9%, P<0.05, *d* = 0.82) spent in high-intensity activities (fast forward skating, forward sprinting and fast backward and sprinting) – particularly in forward sprints (-54.8±20.7%, P<0.01, *d* = 1.07) – in period 3 vs. 1. Detailed analysis of players' time-motion patterns of an international ice hockey game indicates that the capacity to perform intense actions is impeded towards the end of the match (period 3). Assessing performance fatigability may help practitioners to tailor ice hockey-specific training routines to help prevent in-game premature and/or excessive fatigue development.

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INTRODUCTION

Ice hockey is a high-intensity intermittent collision team sport, which requires technical skating skills together with explosive lower- (acceleration and changes of direction) and upper-body (shooting and body checking) efforts [1-3]. A typical ice hockey game consists of three 20-min stop time periods, interspersed by 15-min rest intervals. World-class ice hockey players therefore require a wide range of fitness attributes, which include elevated muscular strength levels [4] as well as highly developed phosphagen and/or glycolytic (anaerobic) [5] and oxidative phosphorylation (aerobic) [1,2,6] metabolic pathways.

Professional ice hockey players typically perform (i.e., effective playing time) during 15-24 min (up to 35 min in some cases) of the 60-min game extended over ~3 hours [1,7]. Previous analysis of the game indicated that a typical shift lasts ~30-80 s and is followed immediately by 3 to 5 min of passive rest on the bench between shifts [2,3,7-9]. At the professional level, the game is characterized by intense bouts of play lasting 45 to 60 s, yet seldom exceeding 90 s. Within a shift, there are typically 5-7 activity bursts ranging in duration from 2.0 to 3.5 s and an average total burst duration per game of 4-6 min. Overall, this led to average skating velocities of ~14 $km \cdot h^{-1}$ (ranging from 3 to 24 $km \cdot h^{-1}$) [10], average distance of 5160-7200 m [2,11] and blood lactate levels varying from 8.7 to 15.1 $mmol \cdot L^{-1}$ [7]. Very few studies have used time-motion analysis (i.e., time spent in different locomotor categories) during an ice hockey game. In one study, Dillman et al. [12] reported movement and velocity patterns (i.e., acceleration, deceleration, gliding) of a single player during a one-off ice hockey game where high-intensity skating accounted for 49% of all actions. In contrast, Bracko et al. [13] showed that gliding (39%) was the most common movement pattern. However, these observations were made with a rather limited number of subjects (e.g., one player; [12]) or were restricted to specific positional play (e.g., only forwards; [13]). Additionally, analysis of time-motion patterns was detailed for 30 s from the start of a shift over an entire game [13]. While the aforementioned studies undoubtedly have brought insights in our knowledge of the physical demands of ice hockey, they may have lost relevance over time as today's elite ice hockey players are physically "bigger" and have better developed physiological fitness when compared to their predecessors [1,14]. Consequently, it is unclear how time-motion aspects of elite ice hockey have evolved over the last decades.

In other team sports with unlimited substitutions (i.e., basketball, field hockey, Australian football) [15-18], a reduction in high-intensity activity across playing periods has been suggested to indicate game-related fatigue development [16,17]. Reportedly, greater decreases in high-intensity and total activity frequency, duration and distance were observed in the third and/or fourth compared with the first/second quarter in professional basketball players [16]. Similarly, between-quarter variation has also been reported in Australian footballers, with lower total and high-intensity distance covered in the second, third and fourth quarters compared to the first quarter [17]. However, most of the available ice hockey time-motion analyses have been used to describe on-ice activity, in addition to primarily determining player's physiological requirements during a game [7,19,20], but not to describe the changes in the players' game behaviour induced by the development of fatigue. Arguably, time-motion analysis by game periods would allow a better understanding of specific fatigue development in ice hockey.

Re-examining the pattern of play is necessary since it is commonly believed, among the coaching community, that shift durations are now shorter and intensity of play higher, although it remains to be verified. In ice hockey, as in all team sports, the ability to repeat sprints or high-intensity actions is likely paramount [21]. However, it is currently unclear to what extent "modern" ice hockey players experience fatigue as potentially indicated by reductions in total distance covered and/or in high-intensity activities in the second and/or third periods compared to the first one. The aim of this study was therefore to re-examine changes in time-motion patterns of elite male ice hockey players during an official international game, with special reference to the development of fatigue. As in other team sports, it was hypothesized that the reduction in high-intensity activities with the development of fatigue would be greater than that in the low-intensity ones. Such time-motion profiling would be helpful to provide specific recommendations for the design of strength and conditioning programmes of ice hockey players.

MATERIALS AND METHODS

Subjects

Ten male elite ice hockey players (mean ± SD, age: 24.4 ± 2.6 years; height: 179.3 ± 5.0 cm; body mass: 81.8 ± 6.0 kg), belonging to the same national team, participated in the study. All participants were field players (no goalkeepers) and regularly trained/played in NHL (i.e., 3-4 matches, 2-3 recovery sessions, 2-3 on-ice training, and 1-2 off-ice conditioning sessions per week during the in-season period) or top European squads (i.e., 1-2 matches, 1-2 recovery sessions, 4-5 on-ice training, and 2-3 off-ice conditioning sessions per week during the in-season period). No specific criteria were employed for the selection of players other than being free of either acute or chronic injury in the previous three months and purposed to play the whole game. While this study conformed to the recommendations of the Declaration of Helsinki for use of human subjects, our data arose as a condition of employment in which players carried out their usual match activities [22]. Therefore, the usual appropriate ethics committee clearance was not required. Nevertheless, to ensure team and players' confidentiality, all data were anonymized before analysis. No instruction was given to the players regarding style of play, nor was the coach requested to alter his approach in any way. Of note, the team observed used a 2-1-2 system with 4 units of forwards and 3.5 units of defenders.

TABLE 1. Locomotor categories used for time-motion analysis.

Activity	Criteria	Mean velocity ($km \cdot h^{-1}$)
low-intensity		
standing	motionless	0 $km \cdot h^{-1}$
gliding	motion without propulsive action	~11 $km \cdot h^{-1}$
slow forward	propulsive motion with the trunk slightly forward	~15 $km \cdot h^{-1}$
backward skating	propulsive motion with slow skating rate	~15 $km \cdot h^{-1}$
high-intensity		
fast forward skating	vigorous motion with more forward inclination of the trunk	~22 $km \cdot h^{-1}$
forward sprinting	maximal effort with drastic forward lean	~30 $km \cdot h^{-1}$
fast backward and sprinting	vigorous motion and maximal effort with fast skating rate	~18 $km \cdot h^{-1}$

Procedures

Based on a cross-sectional design, time-motion data of players were recorded by one VHS video camera (NV-M50, Panasonic, Germany) with fixed fields of vision (i.e., positioned at the side of the ice rink, equally distant from the midfield and goal lines, at a height of about 15 m and at a distance of 30-40 m from the ice rink, allowing all player activity to be recorded in one view) with sampling frequency of 50 Hz during a one-off official international game (i.e., World Championship). The videotape was later replayed using commercially available software (Dartfish Prosuite, Fribourg, Switzerland) which allowed a frame-by-frame analysis of each playing sequence for computerized coding of time-motion patterns [23,24]. The match was scheduled at 15:00 in an ice hockey arena maintained at 13.3°C ambient air temperature and 65% relative humidity. Prior to face-off, an official 20-min warm-up period (i.e., including free skating and active stretching, technical/shooting exercises and tactical simulations (breakout and attack 3 vs. 2)) was allowed and was followed by a 15-min resting period (i.e., time requested for ice surfacing).

For whole game analysis, characteristics such as effective playing time (i.e., with the puck in play), stoppage time (i.e., due to puck outs, fouls, goals, injuries), length of the bench resting period between shifts, and number of shifts were recorded and expressed in frequency, mean time and percentage of total effective time. Finally, passing, shooting and body checking were also monitored.

For across-period analysis, the following locomotor categories were used [13]: (i) low-intensity activities (i.e., standing, gliding, slow forward and backward skating) – and (ii) high-intensity activities (i.e., fast forward skating, forward sprinting and fast backward and sprinting) (Table 1). The time it took for a player to travel between pre-established markers on the ice rink (e.g., the distance from the blue line to another known distances) was used to calculate the mean velocity for each category. According to the soccer-based methods previously described [23,24], the frequency and duration of each category were recorded for each of the three periods of the game; the distance covered for each category within each period, as well as within the entire game, was determined as the product of the total time and mean velocity of this particular category; and the total distance covered during the game was calculated as the sum of the distances covered for all categories. To avoid any inter-observer variability, all players' activities were analysed by the same experienced observer. However, to provide a reliable single analysis, both the intra- and inter-observer reliabilities were established. The intra-observer reliability of the present study was deemed acceptable for all locomotor categories, having displayed an adequate intraclass correlation coefficient (ICC) ranging between 0.90 and 0.97 for three separate measurements of seven players, interspersed by 5 days. For each variable, the ICC was in the range 0.90-0.99 for the analysis of the same random period of the game by two experimented observers.

Statistical analyses

Statistical analyses were conducted using Sigmaplot 11.0 software (Systat Software, San Jose, CA, USA). Normal distribution of the data was tested using the Shapiro-Wilk test. Differences between the first, second and third period were determined using one-way ANOVA with repeated measurements (time). In case of a significant difference between treatments, a Tukey post-hoc test was used to identify the specific differences. Cohen's *d* was calculated to determine the effect size between playing periods with its magnitude interpreted as trivial <0.2, small 0.2-0.4, moderate 0.5-0.7 and large >0.8 [25]. The level of significance was set at $P<0.05$ and data were reported as means ± SD.

RESULTS

Time-motion patterns for the whole game

Total and mean effective playing time was 16.1±3.6 min across the game and 5.4±1.2 min per period, mean total distance covered was 4441±972 m, and mean velocity was 16.55±3.62 $km \cdot h^{-1}$. Each player performed ~7.4±1.8 shifts per period of an average duration of 85.72±4.89 s including 44.01±5.71 s of effective playing time and 41.71±4.07 s of stoppage per shift (Table 2).

TABLE 2. Shift characteristics per period during the official international ice hockey game.

Period	Effective playing time (min)	Number of shifts	Effective playing time per shift (s)	Stoppage time (s)	Bench time (min)
1	5.7±0.8	7.4±1.0	46.81±4.76	39.24±4.07	3.7±0.5
2	5.0±1.1	7.2±1.8	41.76±5.06	42.41±3.00	4.4±1.5
3	5.4±1.8	7.7±2.4	43.47±6.71	43.48±4.21	5.5±2.0*
Mean	5.4±1.2	7.4±1.8	44.01±5.71	41.71±4.07	4.5±1.6
Total	16.1±3.6	22.3±4.9	132.04±10.45	125.13±22.64	13.5±3.8

Mean ± SD. * (P<0.05), significantly different from period 1.

During the game, low-intensity modes of activity accounted for 82.4±6.0% of the total effective time. This consisted of 15.0±7.9% standing, 23.0±12.6% gliding, 33.2±6.7% slow forward skating and 8.8±7.6% slow backward skating. High-intensity skating accounted for 17.6±6.0% of the total effective time and was composed of 11.7±6.0% fast forward skating, 4.9±3.3% forward sprinting and 3.4±2.4% fast backward skating and sprinting. In addition, players performed 7±1 passes, 1±0 shots and 5±1 body checks per period without a difference between periods.

Changes in time-motion profiles across periods

Mean effective playing time and effective time per shift decreased from period 1 to 3 (-6.8±17.3%, P = 0.18, *d* = 0.71 and -8.5±12.7%, P = 0.20, *d* = 0.24, respectively), resulting in a lower distance covered (-12.8±5.7%, P = 0.16, *d* = 0.46) along with longer stoppage (+8.2±9.8%, P<0.05, *d* = 0.78) and bench resting times (+35.6±34.0%, P<0.05, *d* = 1.26) (Table 2). A detailed analysis of changes in time-motion patterns across successive periods is presented in Table 3.

The number of forward sprints performed was lower in period 3 compared to period 1 (-46.7±32.1%, P<0.01, *d* = 1.12) and 2 (-36.6±40.0%, P<0.05, *d* = 0.76). This was further accompanied by shorter effective time spent in high-intensity activities (-16.8±24.9%, P<0.05, *d* = 0.82) – particularly in forward sprints (-54.8±20.7%, P<0.01, *d* = 1.07) and backward fast skating and sprints (-43.7±16.3%, P = 0.51, *d* = 0.39) – in period 3 compared to period 1. Although distances covered in low- and high-intensity locomotor categories (with the exception of gliding and slow backward skating) were non-significantly shorter in periods 2 and 3 compared to period 1, only forward sprinting was significantly impaired (P<0.01, *d* = 1.17) in period 3 (Figure 1).

DISCUSSION

This study aimed to examine the time-motion patterns of elite male ice hockey players with special reference to the development of fatigue. The main findings were that "modern game" ice hockey places a strong emphasis on high-intensity (~18% of the effective playing time) locomotor activities; and as game progressed, the capacity to perform such intense actions was impeded towards the end of the match (period 3).

During the official international ice hockey game studied here, players executed low-intensity skating activities for the majority of the playing time (~84%), which is comparable to that observed in National Hockey League (NHL) forwards (~76%) [13], but lower than levels typically reported in other team sports (90-95%), such as soccer, rugby and field hockey [24,26,27]. Overall, this confirms that the physical demand imposed on ice hockey players is almost unique across team sports, with ~18% of the effective playing time spent completing high-intensity skating activities. Additionally, as in field hockey and lacrosse, upper-body actions (e.g., passing, shooting, body checking) add to the total energy expenditure.

TABLE 3. Time-motion categories' frequency, mean duration and percentage of total effective time during the official international ice hockey game.

	Low-intensity activities				High-intensity activities		
Period	**Standing**	**Gliding**	**Slow forward**	**Slow backward**	**Fast forward**	**Forward sprint**	**Fast backward and sprint**
Frequency (n)							
1	13±5	13±4	19±3	7±4	10±3	6±3	4±2
2	12±5	16±5	18±6	6±5	11±6	5±3	4±3
3	17±8#	15±8	20±8	6±7	11±4	3±2**,#	2±2
Mean duration (s)							
1	18.81±7.94	15.98±6.09	32.06±7.64	8.21±5.75	10.67±3.61	7.78±5.51	6.63±3.36
2	13.66±7.24	19.49±9.27	24.18±8.86	8.78±5.05	8.52±4.43	4.68±1.70	4.32±1.31
3	16.44±8.01	20.73±11.86	26.26±10.71	10.75±9.44*	9.34±3.90	5.47±2.37	5.10±1.50
Effective playing time (%)							
1	20.1±7.7	18.2±7.0	37.2±7.2	8.2±5.7	12.0±5.9	6.6±4.1	4.0±2.1
2	16.3±8.6*	27.0±13.9*	31.0±6.7	8.1±6.9	11.8±7.3	5.0±2.7	4.0±3.3
3	19.9±7.6#	23.9±15.2	31.4±4.5	9.8±9.6*	11.4±5.1	3.0±2.1**	2.2±1.6*

Mean ± SD. * (P<0.05) and ** (P<0.01), significantly different from period 1; # (P<0.05), significantly different from period 2.

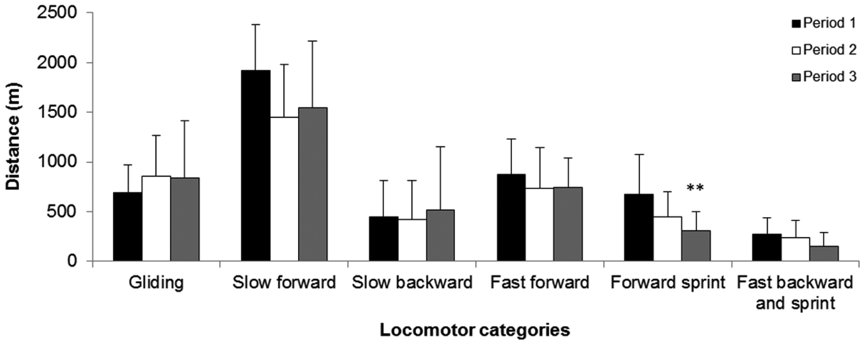

FIG. 1. Distance covered in low- (gliding, slow forward and backward skating) and high-intensity (fast forward, sprinting, and fast backward skating and sprinting) locomotor categories during the first, second and third periods of the official international ice hockey game.
** Significantly different (P<0.01) from period 1.

In line with previous studies [1,7], players analysed here were effectively active during ~16.1 min across the game, corresponding to ~5.4 min per period. Compared to a previous time-motion analysis conducted on Czechoslovakian national team players [11] that reported a total distance covered of ~5160 m (range 4860-5620 m), the shorter total distance covered across the game by our players may be explained by the increase in player units (i.e., 4 units) used in contemporary elite ice hockey. Meanwhile, a higher number of units would place greater emphasis on faster skating velocity [2]. This is further supported by the two-fold higher number of bursts (i.e., ~13 forward sprints vs. 5-7 bursts; [13]) observed for a similar duration (~3.5 s). The average number of shifts per period was ~7, which closely matches the number of shifts (~6.6) counted in varsity [19] or NHL players [28], but is somewhat greater than the ~5.2 shifts also observed in NHL ice hockey forwards [13]. Total shift duration (~85 s) and effective playing time (~44 s) were in comparable ranges as previous studies [3,7,8,13,28].

Passive rest on the bench between shifts is long (~3-5 min) [2,9]. However, the high intensity activity during a shift confirms the utmost importance to play short shifts interspersed with long recovery periods during an elite ice hockey game. Hence, muscle lactate accumulation depends on shift duration, and causes metabolic and contractile disturbances that eventually result in decreased ice hockey performance [6]. Short shifts are known to reduce muscular lactate build-up and the subsequent on-ice recovery period (stoppage) would then be used to partially (~60-65%) resynthesize phosphocreatine (PCr) and restore ATP-PC reserves [2]. Furthermore, the frequency and duration of stoppage encountered across the game may influence time-motion outputs across game periods. In basketball, such data analyses have provided specific insight regarding the fluctuations in activity demands and the influence of recovery opportunity on players' activities [16,29]. Information relative to the intensity and duration of a particular shift as well as the high-intensity bursts within a shift and the frequency and duration of stoppage would provide insight into the respective contribution of anaerobic and aerobic energy pathways in order to increase intensity and/or recovery throughout the game. Further investigation comparing time-motion fluctuations in relation to psychophysiological measures of fatigue across ice hockey playing periods is warranted.

The above statement is particularly relevant in the context of our study, since high-intensity skating activities (in particular forward sprinting frequency, percent of effective playing time and distance covered) generally decreased during the third period of the game, thereby suggesting significant fatigue development towards the end of the match. This may relate to a decreased effective time and/or increased bench rest duration. Since low-intensity activities also declined over time, it is more likely that players experienced fatigue during the game. That said, our findings remain in line with the general consensus prevailing in field-based team sports, which states that greater high-intensity requirements leading to earlier occurrence of fatigue would promote greater declines in performance across game periods at higher playing levels [23,30]. This proposition aligns well with observations made in team sports with unlimited substitutions (i.e., basketball, field hockey, Australian football) [15-18]. For instance, total and high-intensity running distances of elite Australian football athletes significantly decreased from the first to the fourth quarter during a game [17]. Similarly, total activity velocities were lower during the third compared to the first quarter of professional basketball games, leading to decreased high-intensity and total activities as the game progressed [16]. A number of physiological perturbations might have contributed to the decline in time-motion patterns observed here. This may include muscle glycogen depletion, inadequate resynthesis of PCr and ATP, accumulated muscle lactate, lowered muscle pH, interstitial potassium accumulation, temperature elevation, dehydration, central fatigue and muscle damage [1,30-32].

It should be noted that the current data were collected on a specific population during a one-off official international game and may have some limitations. First, this approach may have contributed to lower statistical power for inter-period comparisons (i.e., a-posteriori power value in the range 0.55-0.78). Second, generalization of these findings requires caution as players' responses may vary among teams and competitions due to numerous confounding factors (e.g., individual fitness and technical skills, game score and importance, opposition ability and tactical strategies). For instance, the score in the match studied here was very close and the winner could not be identified until the very end of the match (i.e., 1-1 in period 1, 1-1 in period 2 and 2-0 in period 3, with the two goals scored in the last 30 s of the match). Some potential interaction of opponent's quality, game location, starting period score [33], as well as score differences between winning and losing teams [34] could impact players' time-motion and behaviours. Future research should include a greater number of games evenly dispersed throughout the competitive season among different levels of play to gather a more accurate representation of game demands. In addition, because of (i) differences in rules (e.g., ice rink dimensions) between ice hockey governing bodies, (ii) debate on a wide variety of rule change proposals (e.g., enlarging the goal size, widening the blue and red lines to create a larger offensive zone), and (iii) different timing of rule application (e.g., two-line pass rule abolished in 1998 except for the NHL, which agreed in 2005), regular monitoring may also help us to gain a better understanding of the effects of rule changes ultimately intended to open up the game and improve scoring chances. Finally, considering alternation of accelerating and breaking movements, the contribution of eccentric muscle actions to the total energy expenditure would require specific quantification for improved training recommendations. The recent advancement of local positioning measurement systems for indoor monitoring (i.e., via multilateration with portable satellites) may contribute to deepening our understanding of specific ice hockey activities (e.g., quantifying thresholds for acceleration-based skating volume, skating efficiency). This may notably help to relate specific skating patterns (external outputs) with physiological factors (internal loads), an approach that was lacking in the present study.

Practical applications

The present data are of practical relevance to optimally adapt current on- and off-ice hockey training programmes aiming to improve and/or maintain fitness and offset fatigue development, specifically towards the end of the match (third period).

- First, speed endurance training should be given a high priority. This may include brief work bouts (<30 s) with (i) long recovery periods (e.g., ~2 min) to improve high-intensity intermittent exercise performance and overall speed during repeated sprints, and (ii) short rest intervals (i.e., <60 s) to reduce the power decrement and maintain speed development during both repeated all-out and continuous short-term maximal exercises [35].
- Also encouraged are specific strength/power training programmes that ought to focus on repeated maximal effort ability [36] and/or repeated-sprint ability [37] aiming at postponing the observed fatigue.
- Finally, the present data may assist coaches in strategically developing players' recovery and substitution strategies. Large reductions in high-intensity activities across the third compared to the first period indicate that coaches should explore between-period interventions to maximize players' recovery.

CONCLUSIONS

In summary, the results from this contemporary one-off official international ice hockey game indicate that the demands imposed on ice hockey players are unique in comparison to other team sports. Namely, ~18% of the effective playing time was spent completing high-intensity skating activities, with additional upper-body actions potentially increasing the overall physiological load. With the increase in player units used in "modern game" ice hockey, a greater emphasis on high-intensity skating has emerged, with a two-fold higher number of bursts. Another novel finding was that as the game progressed, fatigue developed, as evidenced by the decrease in high-intensity skating activities. Ice hockey, with its particular shift ratio and inter-period format, is also a relevant model to further investigate fatigue development.

Disclosure statement

No potential conflict of interest was reported by the authors.

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